COMPARISON OF CEMENT GROUTS MIXED BY HIGH-SPEED AND LOW-SPEED GROUT MIXERS

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16. ABSTRACT

A series of tests was performed to compare the physical properties of cement grouts mixed by a low-speed paddle mixer with those of grouts mixed by a high-speed centrifugal mixer. Grouts with water-cement ratios of 0.8:1, 1:1, 3:1, 5:1, and 8:1 by volume were tested and compared.

Test results indicated that the difference in the mixer did not significantly affect compressive strength, but the grouts prepared with the high-speed mixer exhibited less bleeding, more water retentivity, and less shrinkage.

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by

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May 1986

Concrete and Structural Branch
Division of Research and Laboratory Services
Engineering and Research Center
Denver, Colorado

SI METRIC

UNITED STATES DEPARTMENT OF THE INTERIOR ★ BUREAU OF RECLAMATION

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

The research covered by this report was funded under the Bureau of Reclamation PRESS (Program Related Engineering and Scientific Studies) allocation No. DF-12, Portland Cement Grouting Research.

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INTRODUCTION

The Portland Cement Grout Research Program is part of the Bureau of Reclamation's PRESS (Program Related Engineering and Scientific Studies) allocation, No. DF-12. The purpose of the program is to gain increased knowledge of portland cement grouting materials and systems used in sealing and stabilizing dam foundations. USBR (Bureau of Reclamation) specifications now require that high-speed colloidal grout mixers be used in the application of curtain grouting, because it is believed that the colloidal mixer will provide a homogeneous mixture and, therefore, a better curtain than the paddle mixer. However, there is no known documentation for this theory.

The main objective of this phase of the Portland Cement Grout Research Program was to evaluate the physical properties of grouts produced by two different mixers, the high-speed colloidal and the paddle mixers. This report discusses the physical properties of grout prepared in each mixer, test parameters, test procedures, test results, conclusions, and recommendations for future research.

CONCLUSIONS

1. All mixes in the testing program produced grouts exhibiting good hydration and good physical properties.

2. Grouts prepared with the high-speed mixer exhibited less bleed water, more water retentivity, and less shrinkage. They also showed up to 20 percent faster flow through a standard flow cone.

3. The compressive strength test results of grout samples indicated no significant strength differences caused by mixer type.

DESCRIPTION OF MIXERS

Chemgrout High-Speed Mixer

The Chemgrout CG650 grout plant (Fig. 1) consists of a colloidal mixer, holding agitator, and grout pump driven by individual air motors. A watermeter (Fig. 2) is included on the unit.

To provide power for the air motors, a 600 ft^3/min air compressor was rented. The air motor that powered the colloidal mixer was found to have a speed range of 1200 to 1400 r/min; whereas, specifications required 1500 to 2000 r/min. The company providing the grout machine unit was notified, and they sent out a larger air motor, which met the required r/min level.

Big Chief Mortar and Plaster Mixer

This paddle mixer was an electrically powered conventional plaster or mortar mixer (Fig. 3) containing four horizontal mixing paddles. Each of these paddles had rubber strips attached to contact the inner wall of the mixer and prevent cement/grout buildup on the mixer walls (Fig. 4).

PHYSICAL PROPERTIES TESTS AND PROCEDURES

The physical property tests were performed according to standard ASTM (American Society for Testing and Materials), Corps of Engineers, or USBR test methods. An essential part of these, and all test methods, was recording observations of physical characteristics, such as cracks, deformations, and discolorations, for all specimens. A summary of the grout mix tests is listed in Table 1. All water-cement ratios listed in this report are by volume in accordance with accepted U.S. practice.

The physical properties investigated in this study are listed, and their test procedures are described below.

Unconfined Compressive Strength

Strength is a good indicator of durability for mortar and concrete mixtures, and it gives a good idea of the physical adequacy of grouts. The standard test method, ASTM C 39, Compressive Strength of Cylindrical Concrete Specimens, was followed for unconfined compression tests with these additional specific procedures:

1. Specimens were cast in 3- by 6-inch cylindrical cardboard molds.

2. All cylinders were capped and then tested. Cylinders were loaded at a rate of 6,000 lbf/min.

Drying Shrinkage

Cementitious mixtures with high water contents, such as grouts, usually undergo shrinkage caused by evaporation of water. This shrinkage, termed "drying shrinkage," could hinder the impermeability of a grout curtain. After crevices in foundation rock are sealed, drying shrinkage could cause minute cracks where grout pulls away from rock surfaces. Drying shrinkage testing (Fig. 5) was performed according to ASTM C 157, Standard Test Method for Length Change of Hardened Cement Mortar and Concrete, with the following exceptions:

1. Most grout mixes were fluid enough to be poured into molds instead of being tamped in layers.

Table 1. – Summary of grout mix tests.

Type of test	Water-cement ratio 0.5:1	0.8:1	1:1	3:1	5:1	8:1
7-day compressive strength	PM*	PM-HS†	PM-HS	PM-HS	PM-HS	PM-HS
28-day compressive strength	[1]	PM-HS	PM-HS	PM-HS	PM-HS	PM-HS
Drying shrinkage	[1]	PM-HS	PM-HS	[2]	[2]	[2]
Permeability	[1]	[3]	[4]	[4]	[3]	[3]
Water retentivity	PM	PM-HS	PM-HS	PM-HS	PM-HS	PM-HS
Banding	PM	PM-HS	PM-HS	PM-HS	PM-HS	PM-HS
Flowability	PM	PM-HS	PM-HS	PM-HS	PM-HS	PM-HS
Bleeding	PM	PM-HS	PM-HS	PM-HS	PM-HS	PM-HS
Viscosity	PM	PM-HS	PM-HS	PM-HS	PM-HS	PM-HS
Petrographic examination	PM	HS	PM-HS	PM-HS	PM-HS	PM-HS

* PM = Paddle mixer
† HS = High-speed mixer
[1] Testing discontinued
[2] Specimen too short for testing
[3] Test not attempted because of prior failure because of procedure
[4] Test attempted but failed because of procedure

2. At an age of approximately 24 hours, the specimens were removed from their molds. They were not placed in water for 15 minutes or longer as designated, nor were they cured in lime-saturated water until 28 days' age.

Initial comparator readings were taken at 7 days. After the 7-day reading, the specimens were placed in the 50-percent relative humidity room until the second reading, which was taken at 28 days. Length changes of specimens were determined on the basis of these two readings.

Permeability

When grout completely fills the voids in foundation rock, a grout curtain is formed that is practically impenetrable by water flow. However, if hardened grout is permeable, it would allow water to seep through this grout curtain. Hardened grouts were tested under high pressure to evaluate their permeability.

The apparatus and test method were adapted from those used by the USBR in testing permeability of concrete. A drawing of the permeability equipment is shown on Figure 6. The test procedures are summarized below:

1. Specimens were cast as 6-inch-diameter by 12-inch-long cylinders. These cylinders were then sawed to form 6-inch-diameter by 6-inch-long specimens. However, grouts with water-cement ratios of 5:1 and 8:1 formed cylinders much less than 12 inches long, due to settling of cement particles. It was not necessary to saw these specimens. All specimens were sandblasted to expose rough grout surfaces.

2. The diameter and length of each specimen was measured to the nearest 0.05 inch.

3. Specimens were sealed in containers and placed in the same vertical orientation in which they were cast. Each container had a 5-inch-diameter hole in the bottom to allow outflow of water during testing. Grout specimens were seated on the bottom flange of the containers with plaster of paris. Stearin pitch was then poured around the specimens to seal the space between their outer surface and the container walls.

4. Lids were fastened on the containers using a lead gasket. The assembled containers were connected to a testing unit.

5. Water reservoirs were pressurized to 400 lbf/in^2, and this pressure was allowed to reach the specimens by opening valves at the tops of the containers.

6. Inflow readings were taken from graduated gauge glasses. Readings were taken every 24 hours over a test period of 670 hours.

7. The coefficient of permeability (K) is derived from D'arcy's law for viscous fluid flow through small connected voids. It states that, for constant physical conditions, the unit rate of discharge is proportional to the hydraulic gradient. That is:

$$Q = KA\left(\frac{H}{L}\right)$$

where:

K = coefficient of permeability in ft/yr,
Q = inflow in ft^3/yr,
L = thickness of specimen in ft,
A = cross-sectional area of specimen in ft^2, and
H = water pressure head in ft.

Permeability for concrete is defined as the volume of water that passes through a 1-ft^2 area at a unit hydraulic gradient in 1 year.

Water Retentivity

This test determines the water retained in a grout sample. The measurement was performed less than 1 minute after the grout sample was taken from the mixer. The time required to extract 60 mL of water from each sample was recorded for comparison. Corps of Engineers' test method CRD-C 612 was followed.

Banding

To ensure that a homogeneous mixture had been attained, a watertight box 2 to 3 inches deep was filled with fresh grout and cured in 100 percent relative humidity. The hardened specimen was then broken to see if there was any banding, which would indicate that the mix was not homogeneous.

Flowability

A comparison of flowability of all mixes was provided by the Corps of Engineers' flow-cone test CRD-C 611. This test involves the procedure used both in the laboratory and in the field for determining the flow of grout mixtures by measuring the time of efflux of a specific volume of grout from a standard flow cone.

The inside surface of a standard flow cone was moistened, and a finger was placed over the outlet of the discharge tube. The grout was introduced into the cone until it rose into contact with the point gauge. Then the stopwatch was started and the finger was removed from the outlet simultaneously. The watch was stopped at the first break of continuous discharge from the cone, which was then essentially empty. When there was a break in the continuity of discharge before the cone was essentially empty, the grout was too thick to be properly tested for flow by this method.

Bleeding

In cement mixtures having high water content, bleeding is a concern. Bleeding is the rise of water to the top surfaces of grout caused by the settling of solid particles. In grouting technology, it is assumed that much of the water in a grout mixture is forced out into foundation rock during pressure pumping. Grout specimens cast in the laboratory under atmospheric pressure do not experience the same conditions as grout pumped into foundation rock. Therefore, the bleeding characteristics of the laboratory specimens are only indications of field performance. In the bleeding test, an equal volume sample of each water-cement ratio was taken from each mixer and poured into a graduated cylinder. The cylinder was covered with aluminum foil secured with a rubber band to prevent evaporation. Two hours later, the volume of clear bleed water above the grout was determined by observation.

Viscosity

The viscosity of each water-cement ratio grout mix from each mixer was determined with a Brookfield viscometer. The fresh sample of grout was poured into a 100 cm^3 beaker and the viscosity was measured with the Brookfield viscometer. The viscometer was checked for level, and the viscosity was read from the instrument's dial according to manufacturer's instructions.

Petrographic Examination

In addition to the physical properties tests, petrographic examinations were performed on representative samples of the grout mixes. In general, ASTM C 856, Standard Practice for Petrographic Examination of Hardened Concrete, was followed. Specimens were examined megascopically, microscopically, by x-ray diffraction, and by differential thermal analysis. The x-ray and thermal analysis examinations complied with the standard practices of the Chemistry, Petrography, and Chemical Engineering Section of the Bureau of Reclamation.

MATERIALS, MIXES, AND MIXING PROCEDURES

Identical materials, i.e., type II portland cement and tap water, were used for each mix. Six water-cement ratios were used for the comparison study: 0.5:1, 0.8:1, 1:1, 3:1, 5:1, and 8:1. However, the consistency of the 0.5:1 mix was that of a thick paste. Because it could not be mixed in the high-speed mixer, it was judged impractical for testing.

An 8-minute mixing period was used for the paddle mixer, and a 1- to 3-minute period was used for the high-speed mixer. A possible problem was noticed in the mixing tank of the high-speed mixer: steel flanges in the mixer tank prevented formation of a vortex (Fig. 7). A vortex acts as a centrifugal separator. The unmixed cement and grout that is thicker than average is spun to the outside of the vortex, from where it passes to the mixing rotor revolving at high speeds. This process breaks lumps of cement into individual particles, removes absorbent gas layers, thoroughly wets each cement particle, and produces a grout that resembles a colloidal solution rather than a mechanical suspension. The vortex continues to spin any thicker grout, together with the adjacent slightly thinner grout, back to the mixing rotor. The resulting grout becomes progressively thinner until all grout in the vortex has reached uniform thickness.[1]

TEST RESULTS

General

The outer surfaces of hardened grout samples, especially the tops, contained a soft, white, chalky, and scaly coating. All samples contained some continuous and some discontinuous shrinkage cracks. The top surfaces of the high water-cement ratio samples also contained numerous closely spaced, rounded, cone-shaped structures.

Unconfined Compressive Strength

Compressive strength tests were conducted for both mixer types and for all water-cement ratios at 7 and at 28 days' age. The 0.5:1 mixture was determined to be too thick and was dropped from the evaluation.

Resulting heights of grout specimens varied because of different amounts of settling for each mix. The apparatus for casting cylinders from grouts with water-cement ratios of 5:1 and 8:1 is shown on Figure 8. PVC standpipes had to extend at least 12 in above the molds to obtain a 6-in high specimen. Because cylinder heights varied, all strengths were corrected to compare with standard cylinders with *L/D* (length/diameter) ratios of 2.0. The results of these tests are listed in Tables 2 and 3.

Drying Shrinkage

No shrinkage values for grouts with water-cement ratios of 3:1, 5:1, and 8:1 were obtained because the cement particles settled so much that gauge studs were not held securely enough in hardened specimens to measure length change.

The high-speed mixes showed less drying shrinkage than the paddle mixes for the water-cement ratios tested (Table 4).

Permeability

Tests for coefficients of permeability were attempted, but results were not attained because the grout/tar bond failed. Several tests were attempted on the high-speed and the paddle mixer for 1:1 and 3:1 ratios. The specimens were dried, and the surfaces were sandblasted then heated to 130 °F before the hot pitch tar was poured around them. During tests in the permeability apparatus, the tar/specimen bond failed seven out of eight times. Therefore, a comparison test with this procedure was judged impractical.

Water Retentivity

In every case except the 8:1 water-cement ratio mixes, the high-speed mixes exhibited greater water retentivity than the paddle mixes. The results of these tests are shown in Table 5.

[1] Bard, Ronald J., *Teton Dam – Foundation Grout Testing Program*, Water and Power Resources (USBR) Service Report No. REC-ERC-79-2, Denver, CO, December 1979.

Table 2. – Unconfined compressive strength tested at 7 days' age.

Mixer type	Water-cement ratio	Compressive strength, lb/in² Specimen A	Specimen B	Average
High-speed	0.8:1	1,920	1,800	1,860
Paddle	0.8:1	2,300	2,130	2,220
High-speed	1:1	2,020	1,930	1,980
Paddle	1:1	1,150	1,420	1,290
High-speed	3:1	390	370	380
Paddle	3:1	320	300	310
High-speed	5:1	270	240	260
Paddle	5:1	250	350	300
High-speed	8:1	80	100	90
Paddle	8:1	190	190	190

Table 3. – Unconfined compressive strength tested at 28 days' age.

Mixer type	Water-cement ratio	Compressive strength, lb/in² Specimen A	Specimen B	Average
High-speed	0.8:1	3,320	2,690	3,010
Paddle	0.8:1	3,620	3,460	3,540
High-speed	1:1	2,720	2,660	2,690
Paddle	1:1	1,660	2,230	1,950
High-speed	3:1	570	500	540
Paddle	3:1	570	570	570
High-speed	5:1	350	430	390
Paddle	5:1	410	490	450
High-speed	8:1	240	140	190
Paddle	8:1	300	300	300

Table 4. – Drying shrinkage tests on 1- by 1- by 11¼-inch prisms.

Mixer	Water-cement ratio	Comparator readings, in 7 days	28 days	Length change	Percent change
PM*-A	0.8:1	11.1499	11.1261	0.0238	0.21
PM-B	0.8:1	11.1974	11.1728	0.0246	0.22
HS†-A	0.8:1	11.1779	11.1601	0.0178	0.16
HS-B	0.8:1	11.1980	11.1799	0.0181	0.16
PM-A	1:1	11.1280	11.0988	0.0292	0.26
PM-B	1:1	11.1198	11.0914	0.0284	0.25
HS-A	1:1	11.1565	11.1452	0.0113	0.10
HS-B	1:1	11.1739	11.1589	0.0150	0.13

*PM = paddle mixer A = specimen A
†HS = high-speed mixer B = specimen B

Table 5. – Water retentivity test results.

Water-cement ratio	Water retentivity, seconds[1] High-speed mixer	Paddle mixer
0.8:1	119	39
1:1	109	37
3:1	25	17
5:1	22	[2]2
8:1	4	14

[1] The time taken to extract 60 mL of water from the grout sample.
[2] This reading seems too low, but the test was repeated with the same results.

Banding

A fresh grout sample was poured into a watertight box and allowed to cure in the fog room. The samples were removed from the forms, broken, and allowed to dry. The high-speed mixed grout having a 5:1 water-cement ratio was the only one to exhibit banding (Figs. 9 and 10).

Flowability

Grout mixes with water-cement ratios of 0.8:1, 1:1, and 3:1 prepared in the high-speed mixer flowed more rapidly than companion paddle mixer grouts. However, at water-cement ratios of 5:1 and 8:1, this trend ceased to be apparent, and the companion mixes exhibited essentially the same flow rates. The test results, which are averages of two tests on each sample, are shown in Table 6.

Bleeding

The results of bleeding tests (table 7) show that grout samples of every water-cement ratio exhibited more bleed water when mixed in the paddle mixer than when mixed in the high-speed mixer.

Viscosity

Readings were taken on fresh grout samples with a Brookfield viscometer in a 500 cm³ beaker. The high-speed mixer gave lower viscosities in the 1:1, 3:1,

Table 6. – Flowability test results.

Water-cement ratio	Time to empty flow cone, seconds[1] High-speed mixer	Paddle mixer
0.8:1	9	11
1:1	8	9
3:1	7	8
5:1	8	8
8:1	8	8

[1] Values are the averages of the two tests on each sample rounded to the nearest second.

Table 7. – Grout bleed-water test results.

Water-cement ratio	Amount of bleed water, mL[1] High-speed mixer	Paddle mixer
0.8:1	no measurable settlement	3.5
1:1	1	4.5
3:1	19	23.0
5:1	33	52.5
8:1	35.5	53.5

[1] Volume of clear water above grout after 2 hours.

and 8:1 water-cement ratios; whereas, the paddle mixer gave lower viscosities in the 0.8:1 and 5:1 water-cement ratios (Table 8). Such results can only be judged inconclusive. They indicate the need for additional testing.

Petrographic Examination

Twelve grout samples were submitted to the USBR's petrographic laboratory for evaluation. Seven samples were prepared by the high-speed mixer and five samples by the paddle mixer. Water-cement ratios varied from 0.5:1 to 8:1. All samples were 3-inch-diameter cylinders and were cured in 100 percent relative humidity for more than 30 days. Samples were sawed in half from top to bottom.

The outer surfaces of the samples, especially the tops, contained a soft, white, chalky, and scaly coating composed chiefly of calcite and calcium hydroxide. Moderate to minor amounts of ettringite, and trace amounts of gypsum were also present.

The sawed interior portions of samples No. PM-0.5:1, PM-1:1, HS-0.8:1, and HS-1:1 were uniform in color from bottom to top.

The interiors of samples PM-3:1, PM-5:1, PM-8:1, HS-3:1, HS-5:1, and HS-8:1 were nonuniform and gradational in color. These samples exhibited visible signs of settlement and discontinuous, irregular light streaks at or near the bottoms. These streaks extended about one-third to one-half way up the samples and were aligned, more or less, parallel to the long, or vertical, axis of the samples.

Table 8. – Grout viscosity test results.

Water-cement ratio	Viscosity, centipoises High-speed mixer	Paddle mixer
0.8:1	1,360	670
1:1	1,080	1,775
3:1	22	48
5:1	7	6
8:1	2	3

All samples displayed shrinkage cracks parallel to the short axis.

The top, white surfaces of the 1:1 to 8:1 water-cement ratio samples contained numerous closely spaced, rounded, cone-shaped structures. These structures were formed by the excess water and water-soluble salts escaping upward along tubular channels because of the settling and compacting of the cement before initial set. X-ray diffraction analyses of representative powdered samples of the grout showed that all samples were well hydrated.

Petrographic examinations and studies revealed essentially no physical or chemical differences between the paddle and high-speed mixed portland cement grout samples.

SUMMARY

1. There was no significant difference in compressive strength of specimens mixed with either mixer.

2. In the drying shrinkage test, the high-speed mixes showed less drying shrinkage than the paddle mixes.

3. The high-speed mixer samples retained more water in every case except with the 8:1 water-cement ratio samples.

4. Banding was only seen in the high-speed 5:1 sample.

5. The high-speed mixer grouts with lower water-cement ratios flowed faster through the flow cone. There was no significant difference in flowability at the higher water-cement ratios.

6. The bleed-water test showed that the high-speed mixer yielded less bleed water than the paddle mixer for every water-cement ratio.

7. The high-speed mixes were less viscous in the 1:1, 3:1, and 8:1 water-cement ratios; whereas, the paddle mixes were less viscous in the 0.8:1 and 5:1 water-cement ratios.

8. Despite irregularities in the appearance of the hardened grout sample, including gray streaks, shrinkage cracks, and a scaly coating (mostly on top), physical or chemical differences in grout quality could not be found by petrographic examination.

Figure 1. – Chemgrout CG grout plant. The mixing tank is the cone-shaped tank in front; the holding and agitation tank is in the rear. P801-D-80956

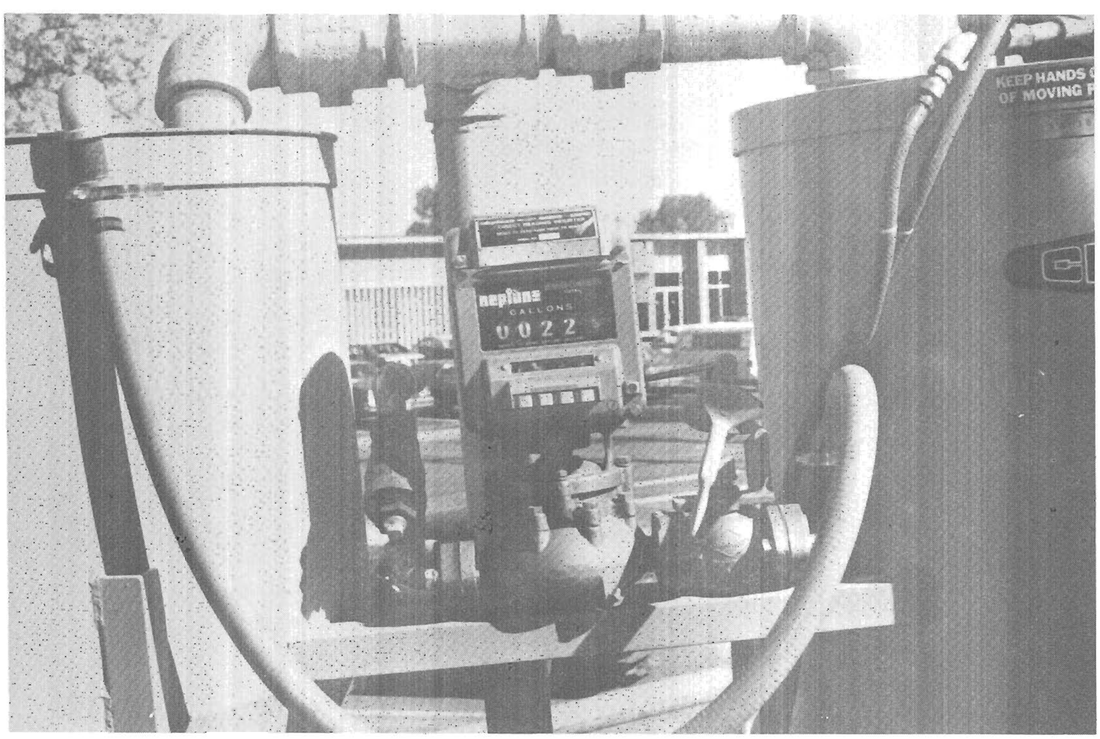

Figure 2. – Watermeter for Chemgrout CG grout plant. P801-D-80957

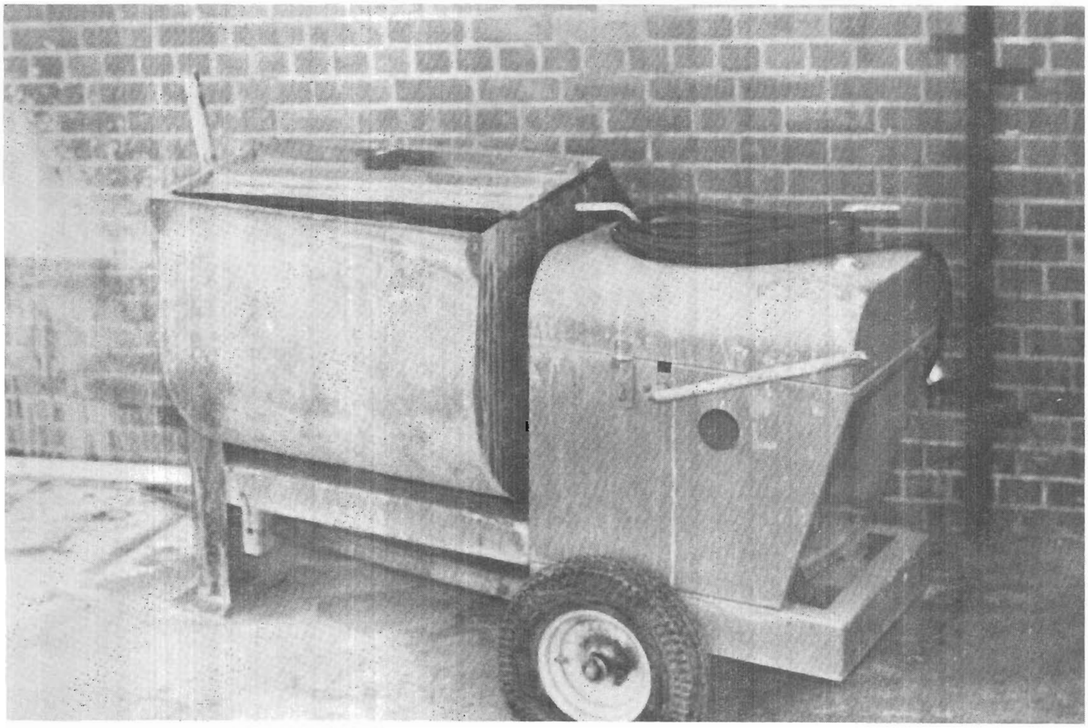

Figure 3. – The Big Chief mortar and plaster mixer, model No. 4. P801-D-80958

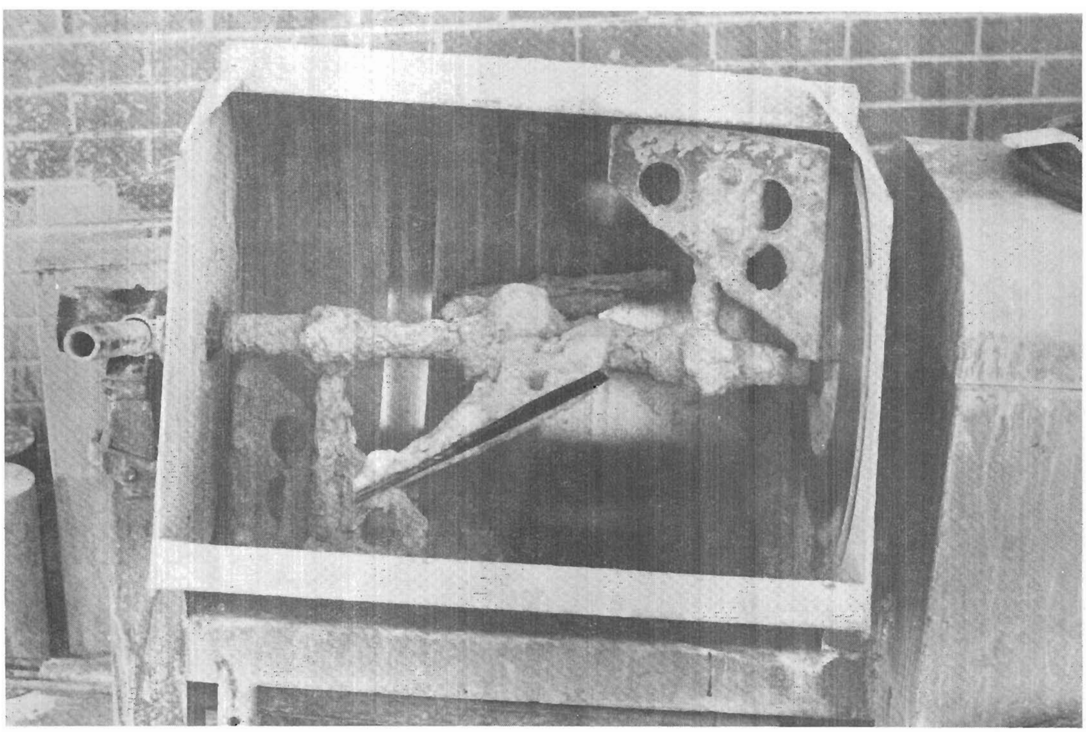

Figure 4. – Inside of the Big Chief mixer drum. The paddles have rubber strips on their ends, which scrape the drum. P801-D-80959

Figure 5. – Typical 1- by 1- by 11¼-inch prism tested for drying shrinkage. Gauge stud is barely visible at left end of bar. P801-D-80960

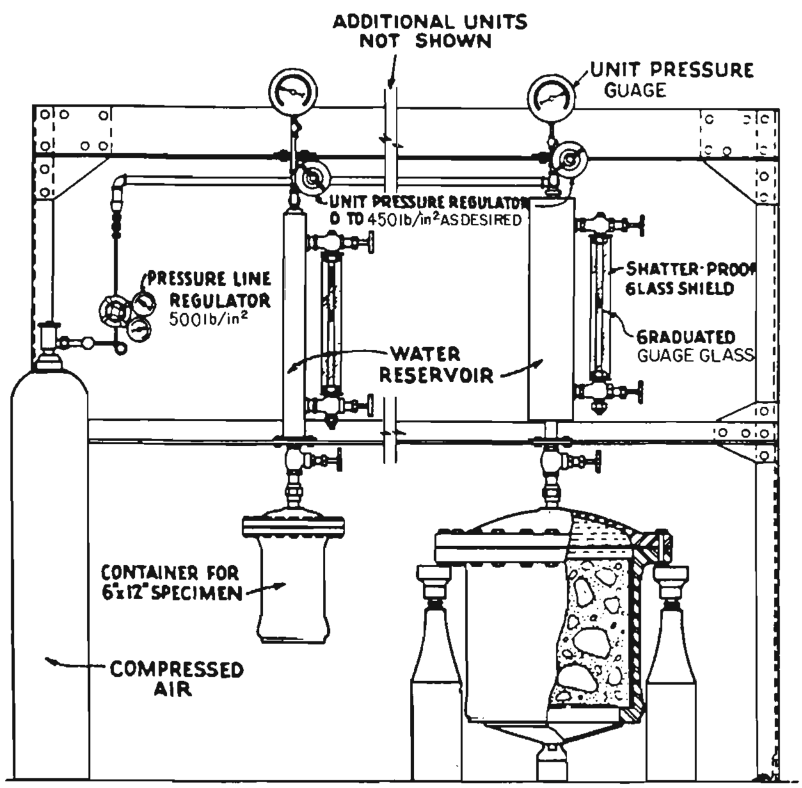

Figure 6. – Permeability test apparatus.

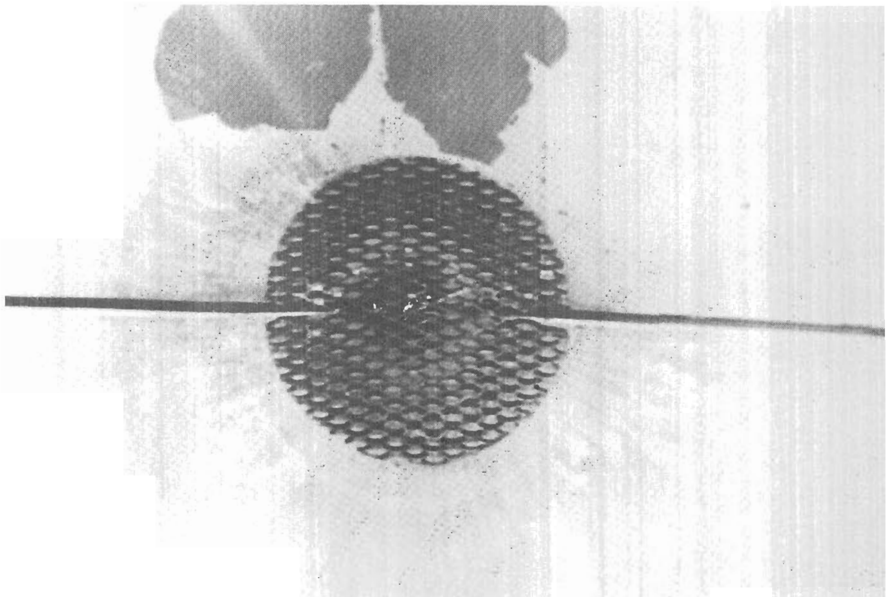

Figure 7. – Inside of the high-speed mixing drum. The steel flanges protruding from the side of the drum prevented the formation of a vortex. P801-D-80961

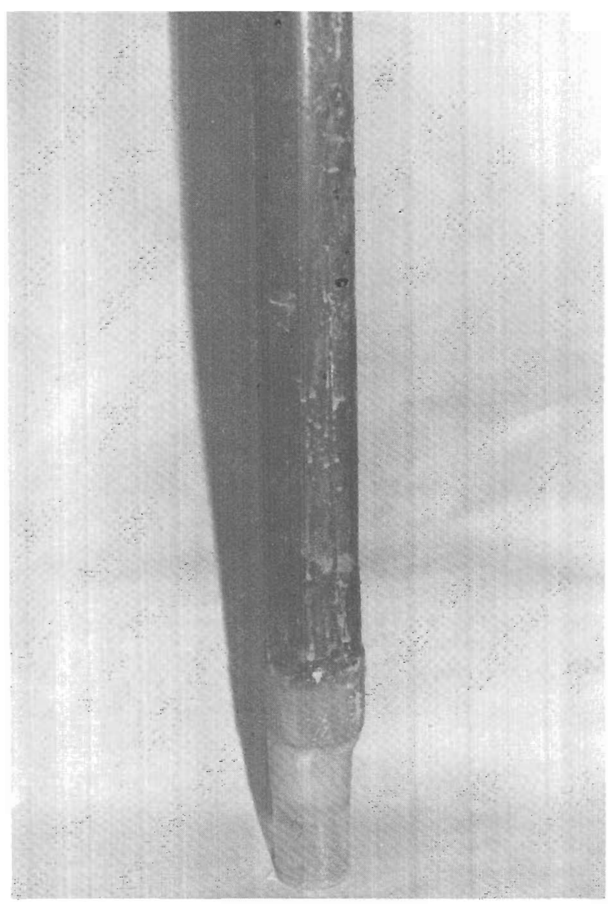

Figure 8. – Apparatus for casting test cylinders using grouts with water-cement ratios of 5:1 and 8:1. The joint between the PVC pipe and the mold is sealed with wax. P801-D-80962

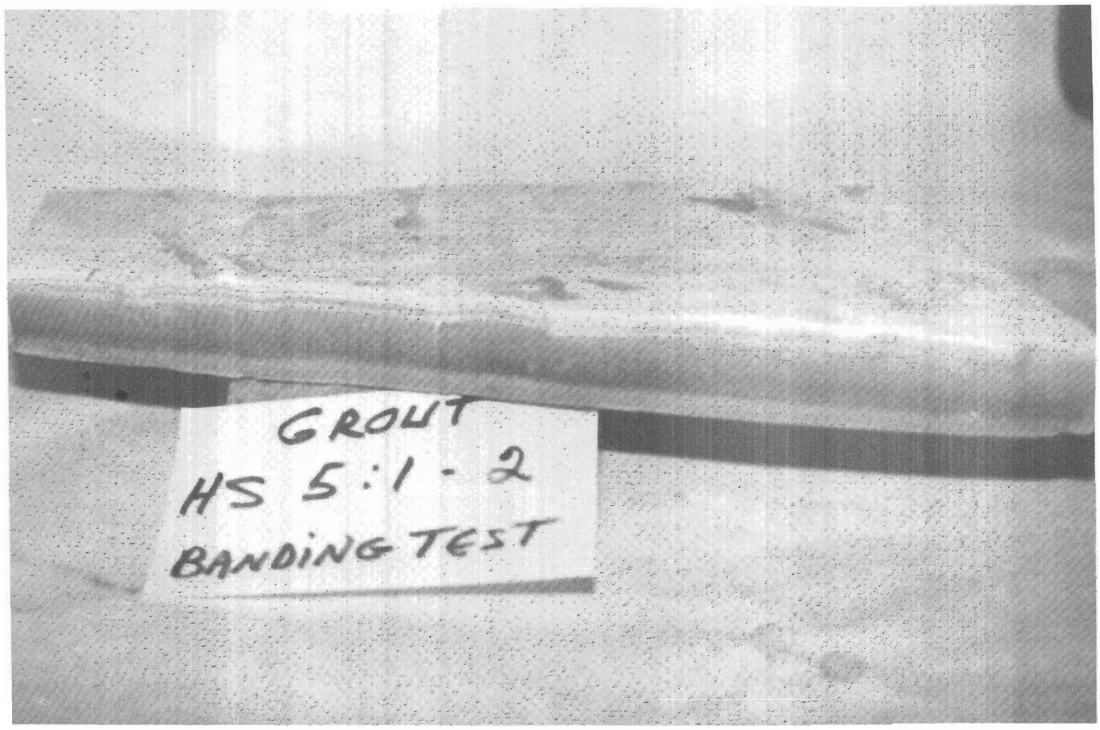

Figure 9. – Evidence of banding in the high-speed mixer 5:1 specimen. P801-D-80963

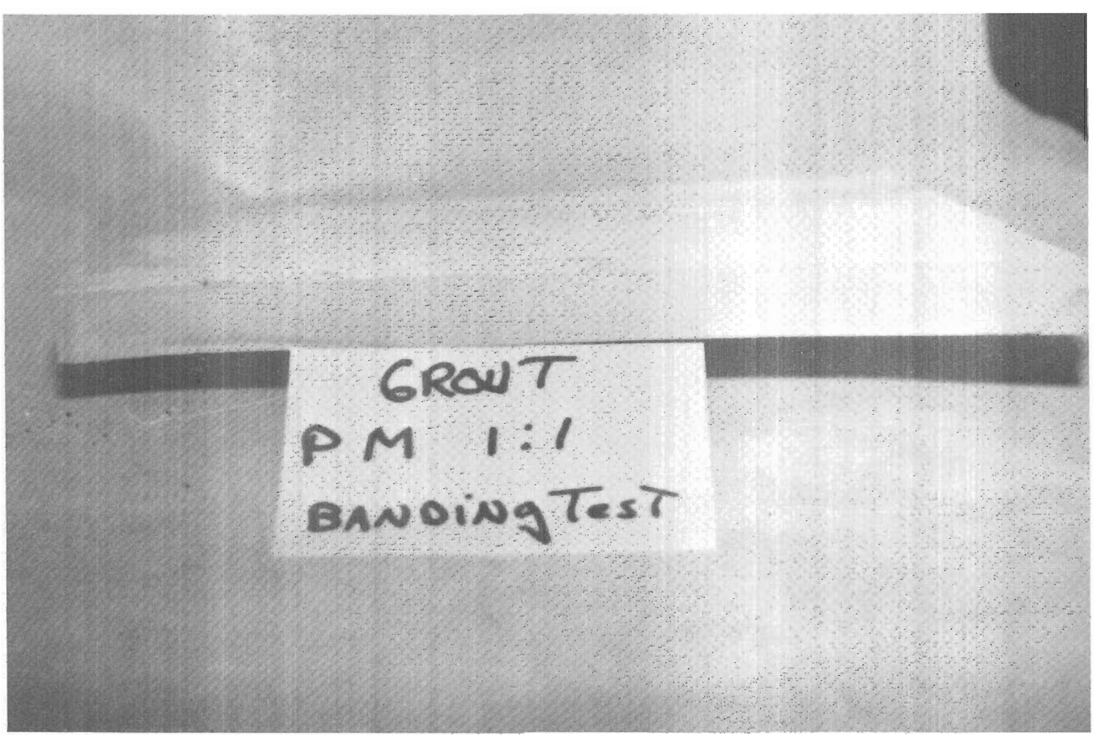

Figure 10. – No banding in the paddle mixer 1:1 specimen. P801-D-80964

GPO 850-957

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-922, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.